THE SHEET OF MYLAR

The large brown envelope accompanying these instructions contains a 3' by 4' sheet of aluminized Mylar which the lecturer can use in his Project Echo demonstration.

Echo I, the inflatable satellite used in the Project Echo communications experiment, is made of Mylar just like this sample.

The balloon has a surface area of 31,000 square feet -- about three-quarters of an acre. It's made of 82 gores of Mylar, each four feet wide and 157 feet long, which were cemented together to form a sphere 100 feet in diameter when inflated.

Mylar is a transparent polyester film made by E. I. Du Pont De Nemours & Co. of Wilmington, Del. The aluminum coating was added to the Mylar used in Echo I so it could reflect microwave signals. The satellite makes an effective mirror: its reflectivity is 98 percent or better for microwave frequencies up to 20 billion cycles per second. The aluminum coating was put on by a vacuum depositing process at the National Metallizing Division of Standard Packaging Corp., Trenton, N. J.

This Mylar is a half-thousandth of an inch thick, or half the thickness of the cellophane on a pack of cigarettes. The aluminum coating is six millionths of an inch thick. Echo I weighs about 135 pounds, including 2-3/4 pounds of aluminum.

Mylar's tensile strength is 20,000 per square inch, roughly one-third that of mild steel. It has an impact strength of 90 kilogram-centimeters and can withstand 20,000 cycles in a flex tester.

Mylar has the highest dielectric strength of any of the plastic films -- 4,000 volts when it's produced in a thickness of one mil. It has a power factor of 0.003 at 60 cycles and a dielectric constant above 3.0 at most frequencies.

Mylar withstands temperature extremes: it has a service range from minus 80 degrees Fahrenheit to 300 degrees Fahrenheit. In Project Echo, it showed it could stand sudden inflation in the super-cold, near-vacuum of a 1,000-mile altitude.

Mylar absorbs less than 0.5 percent moisture. It is unaffected by oils, greases and most solvents; it resists many acids and alkalis.

Because Mylar is so tough, thin and flexible, scientists of the National Aeronautics and Space Administration selected it as the material for the Project Echo satellite. The sphere was developed under the direction of NASA's Research Center at Langley Field, Va. It was fabricated for NASA by the G. T. Schjeldahl Co. of Northfield, Minn.

Chemists at Bell Laboratories were among the first to make the chemical compound which forms the polymer film. They did it in the course of their early program of fundamental polymer synthesis in the late 1930s and early '40s, which was partly stimulated by the research of the late Wallace H. Carothers at Du Pont. However, they did not pursue their work with the material because its properties were not adequately recognized at that time.

Bell Laboratories chemists returned to Mylar after World War II. By that time the polymer, which had interesting electrical properties, had been developed by John R. Whinfield in England and independently by Du Pont in the United States. When the Laboratories chemists learned that Mylar made an excellent dielectric, or insulator, they worked with the Du Pont company to apply their findings. Subsequently, Du Pont began producing Mylar on a large scale as a dielectric for capacitors and for other uses as a film. Capacitors, devices which hold electric charges, are widely used in Bell System equipment.

THE LIFE OF ECHO I

Engineers say that Echo I, orbiting the earth since Aug. 12, has a life expectancy of about one year. A satellite's life span is determined by solar radiation and air drag.

In November, Echo I was still reflecting communications data despite wrinkles that had developed on its aluminum-coated surface.

The wrinkles caused a reduction in the intensity of the signals received. The wrinkles resulted from three factors: (1) loss of gas pressure inside the 100-foot sphere; (2) Echo's path in and out of the earth's shadow where temperature variation is extreme, and (3) the effects of air drag.

Bell Laboratories engineers have been recording the level of signals coming from the satellite and comparing them with technical theory. This helps determine the present condition of the satellite.

By the end of October, experiments were being run only once a week at the Laboratories' Holmdel installation. Primarily, they involved receiving carrier signals transmitted from the U. S. Naval Research Laboratory at Stump Neck, Md.

DESCRIPTION

Lecture Aid No. 214, Project Echo, is a working model of the Bell Laboratories equipment used at Holmdel, N. J., to accomplish space communications via artificial satellites.

The Lecture Aid consists of a Kennedy-type transmitting antenna, a cornucopia (horn-reflector) receiving antenna, a reflecting hemispheric satellite, rods and clamps for mounting the satellite, a photo-mural screen on a stand, two tripods, a cable to connect the receiving antenna to your amplifier, and three carrying cases.

L. A. 214 was designed to be used with the transmitter from Lecture Aid No. 34, Microwave Phenomena. This transmitter is your source of microwave energy. You will have to supply it.

You will also have to supply a source of audio (a record player) to modulate the microwave transmitter. In addition, you will need an amplifier to amplify the signal received in the cornucopia antenna. For this purpose, you can use Lecture Aid No. 198, High Quality Public Address System, or an equivalent unit.

The transmitting antenna is a rear-fed, parabolic-shaped dish 18 inches in diameter. The antenna's waveguide feed carries a 10,000 megacycle microwave signal to its focal point. The antenna exhibits very directional characteristics and concentrates the transmitted signal into a narrow beam. The antenna assembly is aimed by the universal head on the tripod.

The cornucopia receiving antenna has a metalized lucite reflector formed into a paraboloid. The horn portion, which feeds the receiving waveguide, is aluminum. The incoming audio signal is detected by a 1N23B crystal in the box-shaped housing at the rear of the cornucopia. The signal is sent to your amplifier by way of the connecting cable. The antenna is aimed by moving the horn portion, which is on bearings, and by turning the tripod's universal head.

The satellite, a plastic hemisphere, has an aluminum plate fastened to its back surface to reflect the microwave signals. The satellite is attached to the photo-mural assembly with a curved rod and a clamp so that the hemisphere looks like Echo 1 orbiting the earth.

The tripods are equipped with locking handles which keep the antennas in place after they are aimed at the satellite. The tripods can be opened to a maximum length of 69 inches.

The photo-mural should be placed in the center rear of the demonstration stage.

It works like a standard film projection screen: you press the leg release lever located at the legs to open them; then turn the tubular screen container so that it is parallel to the floor.

Clamp the screen rod (the straight rod) to the upper part of the screen support. See Figure 1 on page 12. The notch in the rod should be about six inches from the clamp.

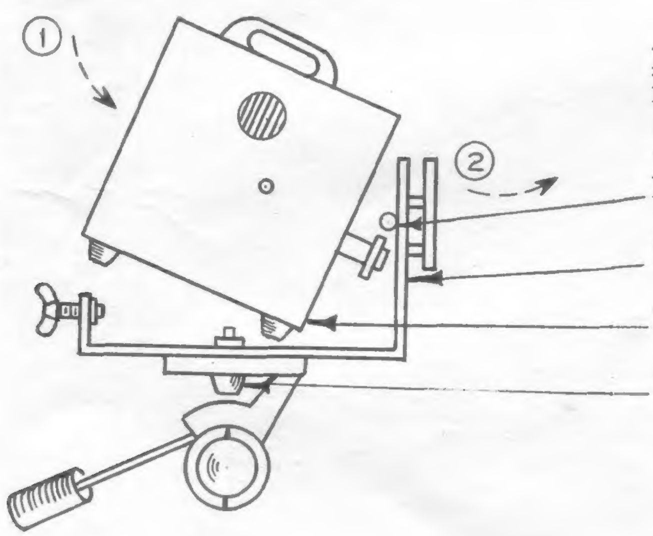
Raise the photo-mural from the screen container and hook its handle into the notch in the screen rod. You may have to adjust the rod later. We will explain this in the "Final Adjustment" section of these directions.

Now raise the screen support until the hole in the photo-mural is at the level of your eye. To raise the screen support, press the button in the sleeve back of the screen container.

We have provided you with a curved rod and a clamp for attaching the satellite to the photo-mural. Clamp the curved rod horizontally to the screen support, making sure the shorter end of the rod protrudes through the hole in the photo-mural. Do <u>not</u> attach the satellite at this time.

<u>The Transmitter</u>

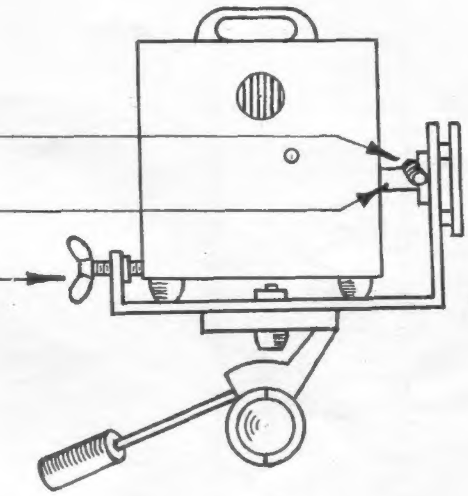
The transmitter assembly consists of four parts: the antenna, the transmitter mounting plate, the tripod, and the microwave transmitter itself.



<u>Figure 2</u>. Install the transmitter with a scooping action, as shown by arrows #1 and #2.

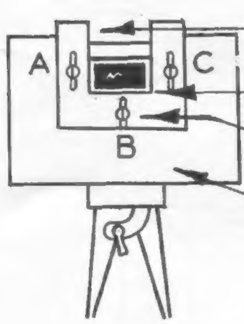
First, attach the transmitter mounting plate to the tripod with the tripod thumbscrew. Next, using a scooping action, place the transmitter on its mounting plate. See Figure 2 on page 13 for these two operations.

Figure 3. The transmitter in place on its mounting plate.



The scooping action will enable you to bring the transmitter's waveguide up under the retaining spring and insert it into the waveguide channel opening. Then tighten the mounting plate thumbscrew against the rear of the transmitter to prevent it from sliding backwards, out of position. Figure 3, above, shows these two operations. Figure 4, below, shows how the waveguide fits into the waveguide channel opening. Caution: the mounting plate thumbscrew is <u>not</u> a locking device -- if you turn it up against the transmitter too tightly you will throw the transmitter and its mounting out of alignment.

Figure 4. Adjustment of the antenna flange retaining plate.



Now adjust the antenna flange retaining plate. To do this, loosen screws A, B and C and adjust the height of the plate so that the bottom edge of the waveguide channel opening is directly in line with the outside lower edge of the transmitter waveguide. See Figure 4 on page 14. Tighten these three screws to complete the adjustment. Arrows #3 and #4 in Figure 5, below, show how the antenna flange retaining plate can be raised or lowered. The broken line in Figure 5 indicates how the waveguide and the channel opening should be lined up.

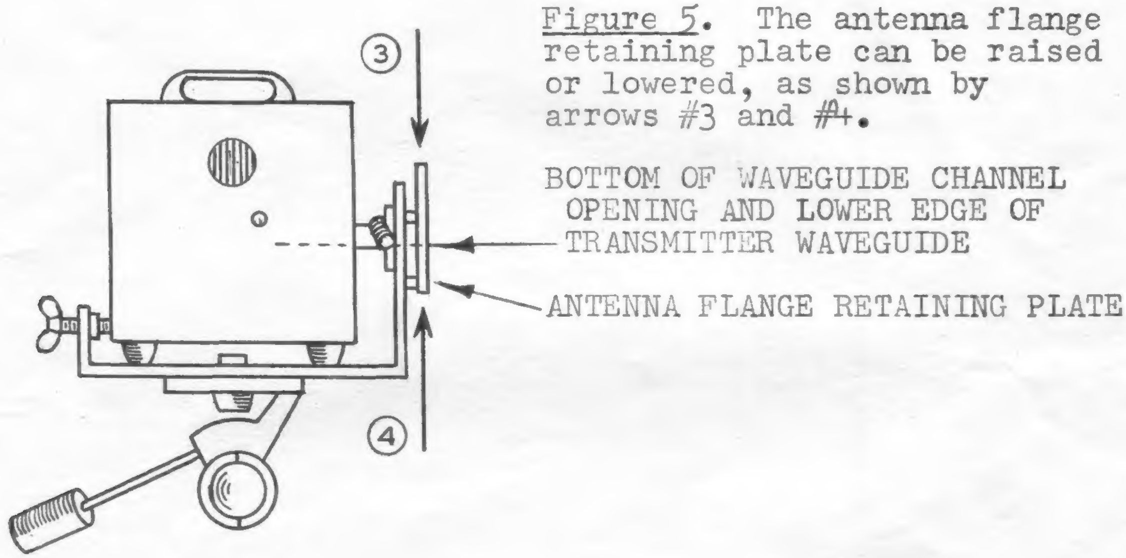


Figure 5. The antenna flange retaining plate can be raised or lowered, as shown by arrows #3 and #4.

Now you are ready to attach the antenna. You do this by sliding the antenna flange between the antenna flange retaining plate and the transmitter mounting plate. See Figure 6 on page 16.

Be sure the antenna is firmly in place. Also, check the alignment of the transmitter waveguide and the antenna feed waveguide by eye. If they are not in line, you probably will have to re-adjust the antenna flange retaining plate. Figure 7 on page 16 shows how the completed transmitter assembly should look.

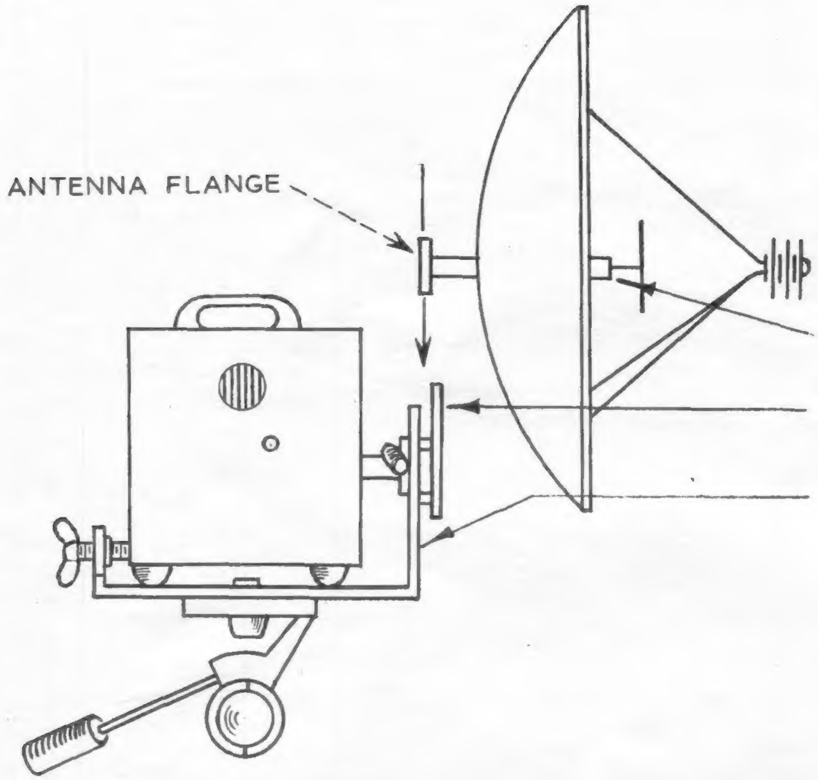


Figure 6. In attaching the antenna, the antenna flange is sandwiched between the transmitter mounting plate and the antenna flange retaining plate.

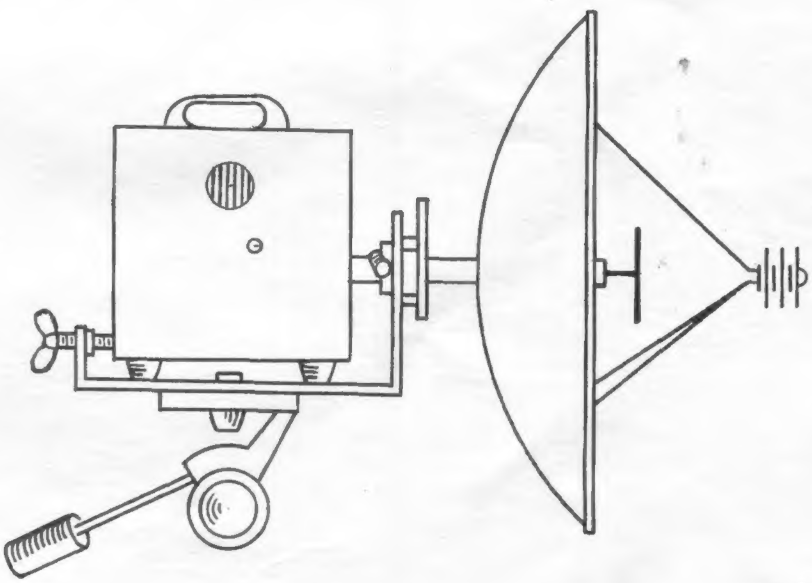


Figure 7. The complete transmitter assembly.

Now aim the antenna at the end of the curved rod, which protrudes from the hole in the photo-mural. Here is one way to aim it: loosen the locking handle on the tripod so the transmitter assembly can be moved easily; stand next to the antenna with your eyes at the same level as the waveguide feed to aim it vertically; then stand back of the antenna to aim it horizontally.

The Receiver

To assemble the cornucopia (horn-reflector) receiving antenna, first attach the circular base to its tripod with the thumbscrew in the tripod head. Next, remove the cover from the box-shaped housing for the microwave receiver at the rear of the assembly. You can remove the cover easily by pressing in on the back of the housing.

Then put the receiver output connections (the red and black leads with the pin plugs) into their corresponding color-coded jacks inside the housing. See Figure 8, below.

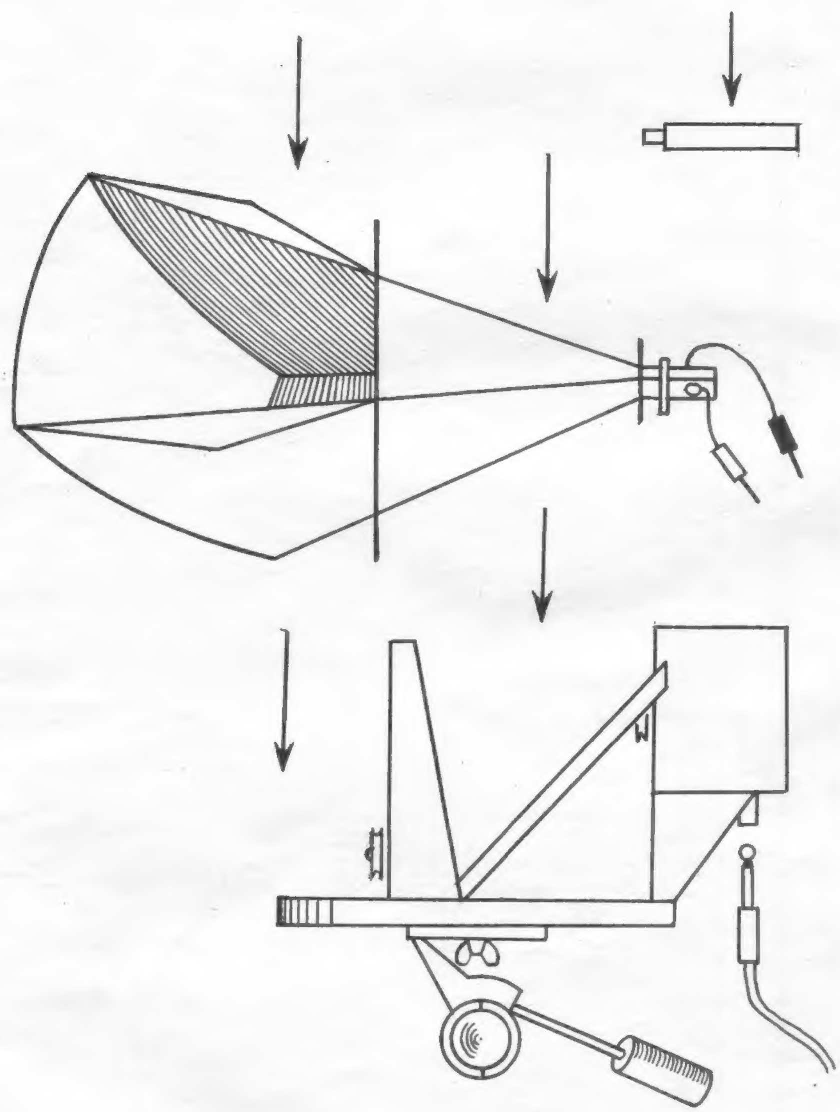


Figure 8. Assembly of the cornucopia antenna.

Now put the cover back on the receiver housing. Be sure to seat it firmly because, as you will notice, it is one of the elements for holding the horn-reflector in position on its base. See Figure 9, below.

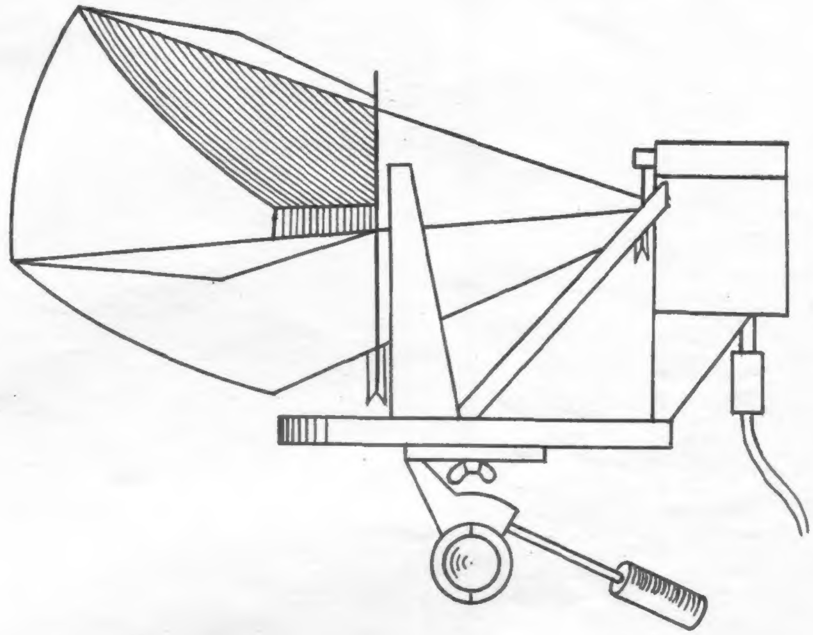


Figure 9. Complete receiving antenna assembly.

To aim the receiver, go back of the photo-mural and peer through the hole. Your line of sight into the cornucopia should be as shown in Figure 10, below.

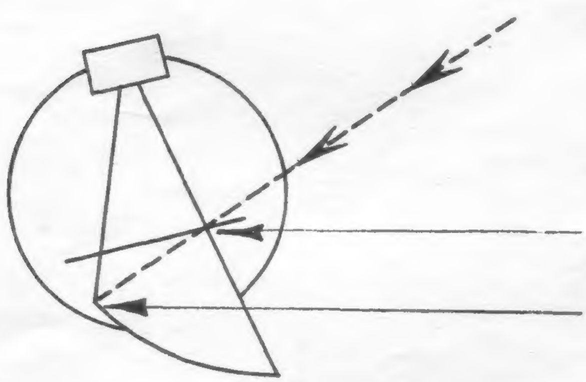


Figure 10. Your line of sight into the cornucopia is shown by the arrows on the dashed line.

BOTTOM EDGE OF ANTENNA OPENING

JUNCTION OF HORN AND REFLECTOR

Now sight along the portion of the curved rod that protrudes through the hole. Your line of sight should be such that the rod points mid-way between the transmitter and the receiver. See Figure 11, below.

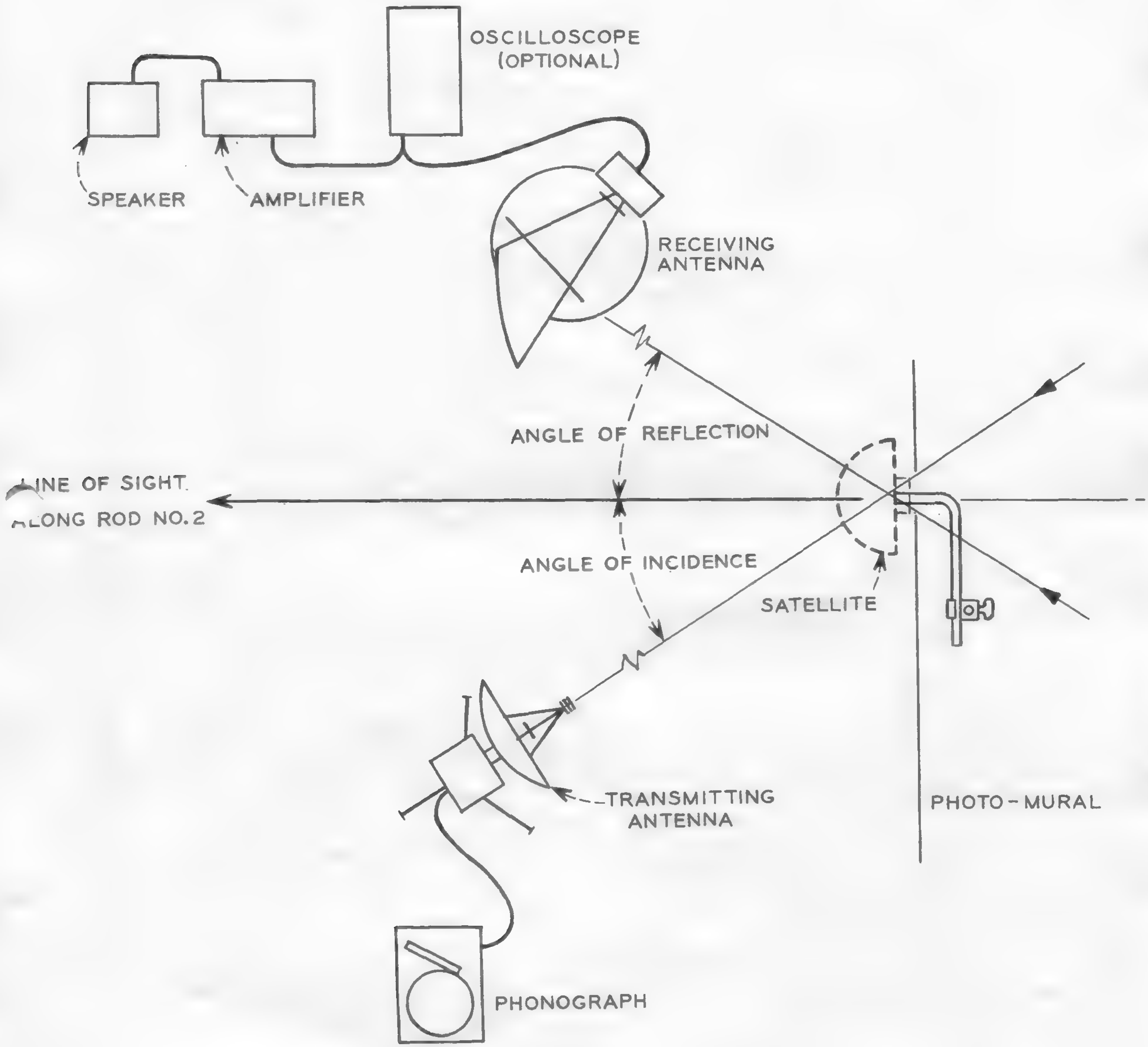


Figure 11. Layout for the complete Project Echo setup.

SETTING UP THE EQUIPMENT

This section tells how to set up the various pieces of equipment for a show. We suggest you follow the steps in the order that we have set down below.

The Photo-Mural

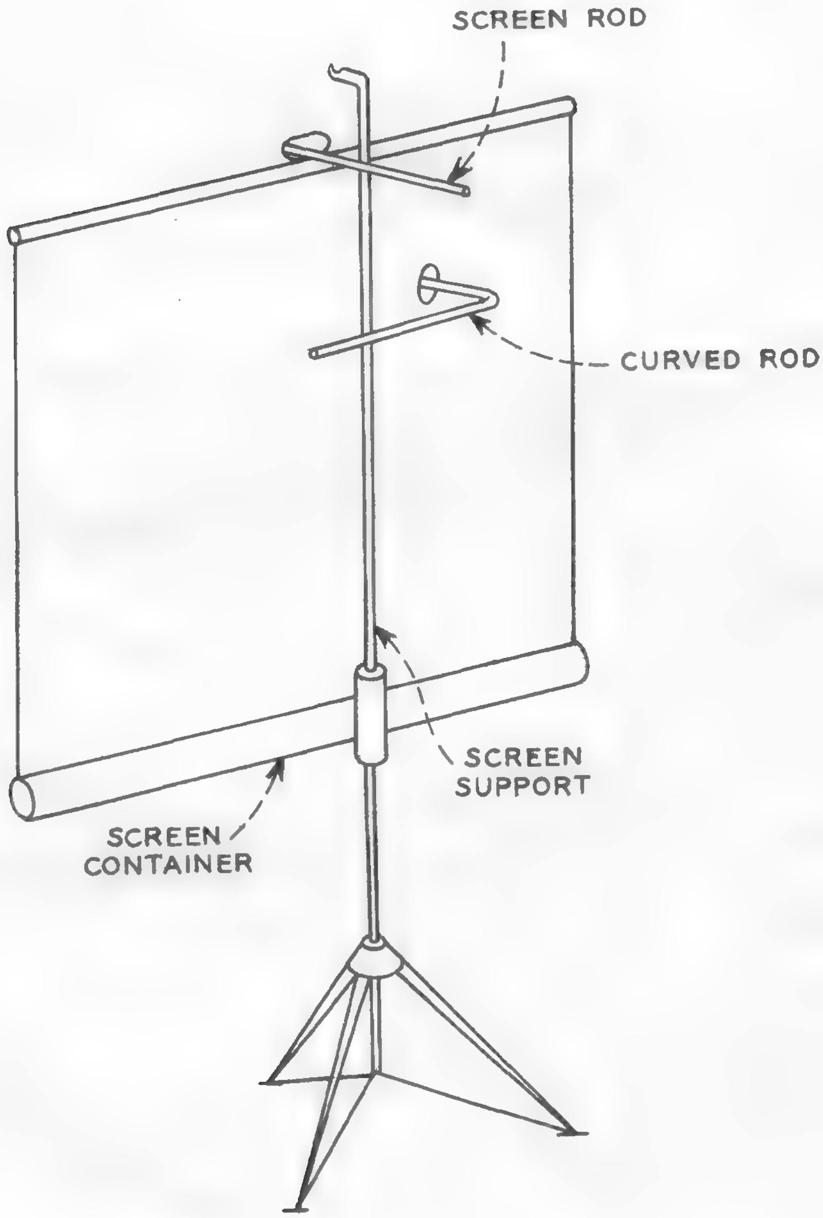


Figure 1. This illustration shows the assembly of the screen and the curved rod-and-clamp arrangement for attaching the satellite.

You probably will have to move your antennas around until they are arranged as shown in Figure 11 on page 19. Then look through the hole in the photo-mural again. You should still see the receiver as shown in Figure 10 on page 18. Also, the transmitter's feed waveguide should be lined up with the ornament as shown in Figure 11 on page 19.

In referring to Figure 11, you will notice that the transmitter is modulated by an audio signal obtained from a record player. The microwave signal bounces off the aluminum plate fastened to the back of the satellite and enters the cornucopia antenna. (The angle of incidence is equal to the angle of reflection.) The receiver is connected to an amplifier and speaker system so that the audience can hear the received signal. The oscilloscope shown in Figure 11 is optional.

The Satellite

To mount the satellite on the photo-mural, slide the flange on its rear surface over the curved rod. Bring the satellite as close as possible to the screen and lock it in place with the screw in the flange. See Figure 12, below.

You may have to move the screen rod so that the screen itself takes a position up close to the satellite. Again see Figure 12.

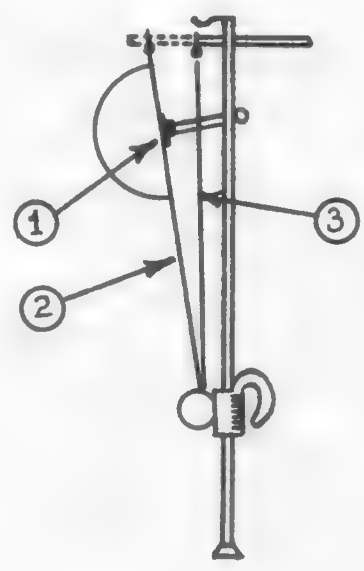


Figure 12. Re-adjust the screen rod (the rod clamped at the top of the screen support) so that the screen is up close to the satellite. The line designated as #2 shows the mew position of the screen.

#1 - SATELLITE FLANGE

#2 - FINAL POSITION OF SCREEN

#3 - POSITION OF SCREEN PRIOR TO RE-ADJUSTMENT

Next, raise the screen support until the entire scene on the photo-mural is visible. You should be able to see a city's skyline silhouetted against the nighttime sky at the bottom of the mural.

Here, you will have to re-aim the transmitter and receiver so that they point directly at the raised satellite. You may only need to point them higher; you may not have to change their orientation to the right or left.

Now turn on <u>all</u> your equipment and allow it to warm up. It will take 10 to 15 minutes for the klystron in your transmitter to warm up.

Turn the transmitter modulator switch to the OSC. (oscillate) position, and set the volume control on the amplifier to about half of maximum. You should hear a low frequency tone which is the signal being transmitted to, and reflected from, the satellite.

<u>Final Adjustment</u>

Now make fine re-adjustments to the orientation of the transmitter, receiver and satellite -- in that order. Do this at least twice to make sure you are getting the maximum signal. This is an indication of proper orientation.

Finally, modulate the transmitter by turning its dial to MOD. (modulate) and playing a record on the record player. This will test the last phase of the operation of the equipment.

You are now ready to present a demonstration of Project Echo.

POSSIBLE CAUSES OF TROUBLE

After you have set up L. A. 214, you may find that the signal is too weak. This condition could have several possible causes. They include:

1. Cross-polarization. Improper orientation of the antennas or unusual orientation, not specified in these directions, could cause cross-polarization. Therefore, one or both of the antennas must be re-positioned to correct this condition. The wave-guide on the receiving antenna must be oriented in the same way as the waveguide on the transmitting antenna; that is, the horizontal axes of both wave-guides must be in the same plane.

2. A defective or weak crystal. You would have to replace the 1N23B crystal in the receiver waveguide located in the box-shaped housing at the rear of the horn-reflector assembly.

3. Improper aiming at the satellite. One or both of the antennas could be aimed incorrectly at the satellite. First, aim the antennas directly at each other, ignoring the satellite. If you get a good, strong signal, you know your equipment is working properly. Then, carefully re-aim your antennas at the satellite.

4. A de-tuned transmitter. To correct this condition, re-tune the transmitter by adjusting the TUNE knob on the front panel. If this does not fully correct the condition, more extensive tuning adjustments may be necessary. The procedure for this is out-lined on page 11 of the instructions for L. A. 34, Microwave Phenomena.

If you get no signal at all, your first job will be to determine which unit is not working properly. Inspect the transmitter first, then follow standard trouble-shooting procedures.

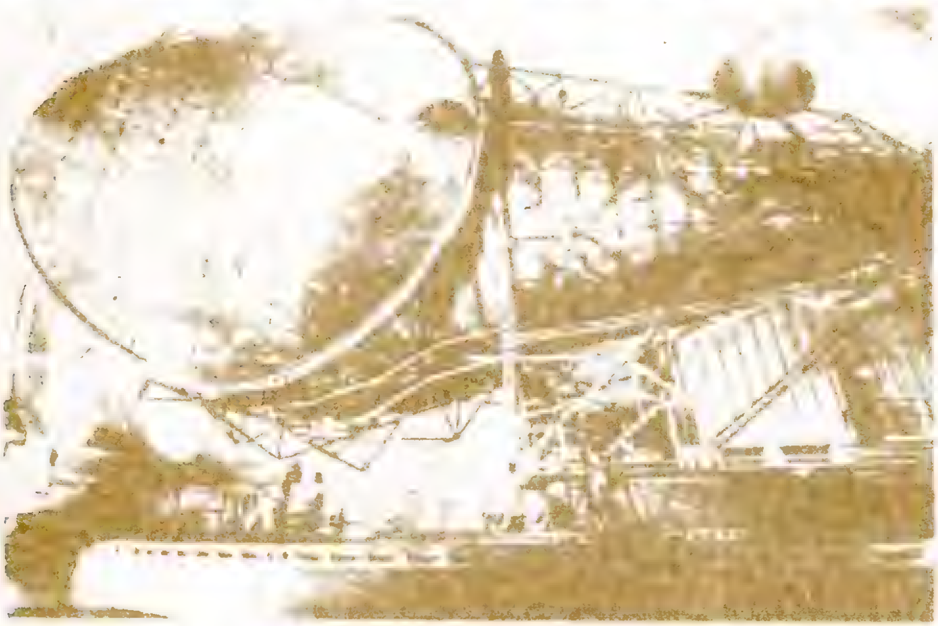
Southern Bell

Management Information Bulletin

EMPLOYEE INFORMATION DIVISION PUBLIC RELATIONS DEPARTMENT
1639 HURT BUILDING ATLANTA GEORGIA 30301

Number 969

COMSAT Plans Commercial Service About June 1



The 380-ton horn antenna at the Bell System's ground station in Andover, Maine, is being used by COMSAT to transmit and receive signals to and from the Early Bird satellite. A 14-foot dish antenna, newly-installed on the cone of the giant horn, sent the first command to turn on the satellite's transmitting equipment.

A thrust-augmented Delta rocket roared off the pad at Cape Kennedy at 6:48 p.m. Tuesday, April 6, successfully launching the Early Bird satellite of the Communications Satellite Corporation. COMSAT hopes to inaugurate commercial service with Early Bird about June 1.

A.T.&T. has leased its Andover station to COMSAT for the Early Bird project. In turn, it plans to lease about 100 Early Bird channels when they're available and if they're of acceptable quality. But A.T.&T. sees a continuing use for undersea cable, as well, to meet growing international communication needs and provide diversity of facilities.

As the satellite went up information about its flight was picked up by tracking stations around the world and immediately transmitted to the COMSAT control center in Washington, D.C. The Bell System's ground station in Andover, Maine, acquired the satellite at 7:03 Wednesday morning.

Bell Guidance System Helps Steer

Early Bird will be placed in synchronous orbit 22,300 miles directly above the equator at a point northeast of Brazil, if all goes according to plan. The satellite was first put into a "transfer" orbit by a three-stage firing of the launch vehicle. The Western Electric-Bell Labs Command Guidance System helped to steer the satellite in its early stages.

Preliminary figures indicate that the satellite is traveling an elliptical path with an apogee of 22,680 miles and a perigee of 900 miles. A "kick motor" in the satellite, turned on by the Andover station, placed the satellite at its proper distance out in space and in position. Precisely maneuvering the satellite to the correct position is expected to take seven to nine days. Once Early Bird is in position, six weeks of transmission and network tests will be made, involving the satellite and the Andover and European ground stations.

Kappel on "Business and the Community"

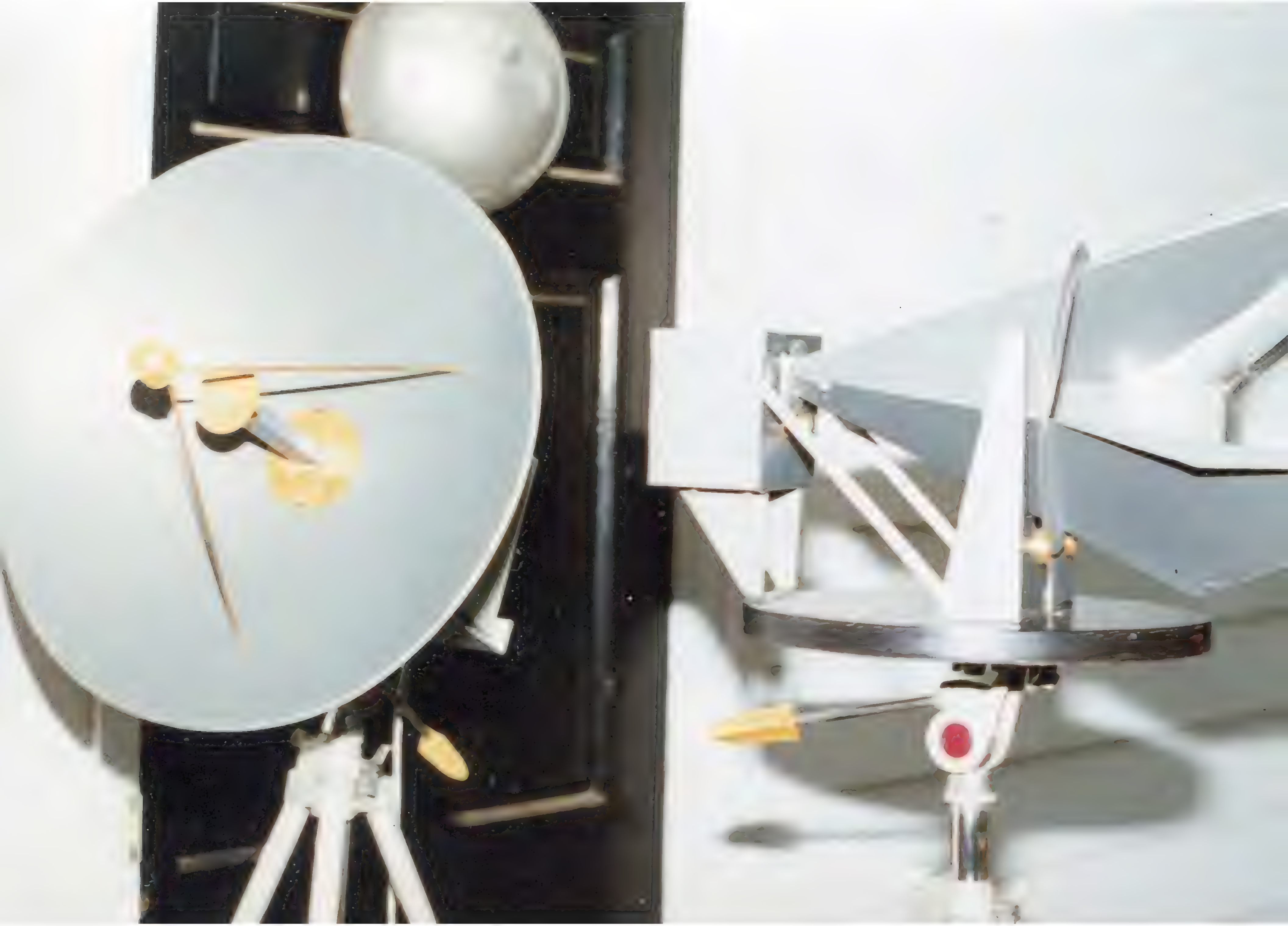
Editor's note: Following are a few direct quotes from A.T.&T. Board Chairman F. R. Kappel's talk before the Rutgers University Annual Business Conference in New Brunswick, New Jersey. The talk is an excellent statement of the responsibility of local management to participate in solving the problems of the community, and the reasons why. Copies of the complete talk in booklet form will be sent to all supervisors.

"This seems to me to be a time of exceptional opportunity, and exceptional need, for real public service. It is an opportunity that should work to business's advantage in every way. In my belief it will enhance public esteem for business. It will enhance the interest of young people in taking up business careers. It will even, goodness knows, enhance the markets that business hopes to serve for years to come."

"Public problems of our day will be solved in the general interest, including the interest of business, only if we make it a regular part of our responsibility to join in the attack. If the problems are ignored by local citizens and business entities, they will have nothing to say about how the problems are settled. And they will not be settled as well, either."

"It greatly disturbs me to hear people say that there is no competency at the local level, that there is only one way out and that is the federal way. I am not the least bit ready to accept that proposition. I think the country should learn the lesson, and the people of each community should teach themselves the lesson, that those who are nearest the problem can deliver the best solution, provided only that they will try."


9



Bell Telephone Laboratories Lecture Aid No. 214

Project Echo

Note to Lecturers:

We believe you will find the accompanying article, "Global Communications via Artificial Earth Satellites", an excellent source of information on Project Echo. Harold S. Black, Systems Research Engineer at Bell Laboratories, is the author.

Mr. Black's invention of the negative feedback amplifier and his successful development of the negative feedback amplification principle has been called one of the most outstanding contributions to telecommunications and allied electronic arts in the past half-century. He has obtained numerous patents for his inventions and has won many honors for his distinguished contributions to communications. For many years Mr. Black has worked in much of the technology on which the successful Project Echo is based.

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1960

November, 1960

Bell Telephone Laboratories Lecture Aid No. 214

Project Echo

GLOBAL COMMUNICATIONS VIA ARTIFICIAL EARTH SATELLITES

by

Harold S. Black

Believe it or not, way back in 1954, Bell Telephone Laboratories was actively interested in satellite communications research; and in 1955 Dr. John R. Pierce, the Laboratories' Director of Research, Communications Principles, published a serious, scientific paper summing up these results. All this, mind you, was a couple of years in advance of Russia's first Sputnik.

Bell Laboratories was farsighted. Without knowledge of how, when, or where a usable communication satellite might be placed in orbit, research groups went right ahead with the creation and development of key components and new technologies prerequisite to successful satellite communications.

Today we profit from the advantages of an early start. The primary objective of our present-day, satellite communications research is to carry television channels and thousands of telephonic messages to all parts of the world by way of artificial earth satellites. This world-wide satellite communications network will include all kinds of linkages and switching facilities and will handle all kinds of messages -- oral, visual, pictorial, telegraphic, high-speed digital, and so on, with requisite speed, requisite security and, of course, complete dependability.

Such a plan for world-wide satellite communications network was outlined by the Bell System in testimony filed in July with the Federal Communications Commission. Under this plan the Bell System would launch its own satellites -- a fleet of 50 active radio-relay spheres spinning like tops. Orbiting in random polar orbits at an altitude of about 3,000 miles, these gyroscopic satellites would, in effect, serve as microwave radio-relay towers 3,000 miles high. They could relay television programs and thousands of telephonic messages across oceans as well as continents.

Briefly, here is what a satellite communication system really is and how it works. Communication satellites may be passive or active. Passive satellites merely reflect radio waves back to earth. Active satellites contain radio receivers and transmitters. Satellites traveling in orbits only a few thousand miles high must be continuously tracked as they move around the earth. Satellites traveling in equatorial orbits 22,300 miles high, and moving in the same direction as the earth rotates, stand still with respect to the earth's surface. In other words, such an equatorial satellite, often referred to as a "24-hour satellite", could serve as a "stationary radio relay"; it would appear to stand still in outer space and it would be continuously visible (at appropriate microwave frequencies) over more than one-third of the earth's surface.

A passive satellite will remind you of radar. Acting as a sky mirror, a passive satellite reflects microwave radio signals. At the sending end, a sharply focussed microwave beam continuously points toward and illuminates (impinges upon) a communication satellite. With isotropic scattering, that part of the transmitted signal which bounces off the satellite is uniformly scattered in all directions. Consequently, whenever the satellite is simultaneously visible to both transmitter and receiver, a bit of this scattered signal reaches the distant receiver. Communication in the opposite direction proceeds similarly. Different radio frequencies, however, are used for the two directions of transmission.

An active satellite will remind you of a land-based microwave radio relay. The electronic equipment carried by an active satellite receives microwave signals, amplifies them, and transmits them back to earth. In the light of present-day knowledge and for many purposes, active satellites are believed superior to passive satellites for reasons of economy, problems of interference, and the ability of ground terminals to use and re-use the same radio frequency.

<u>Project Echo</u>

During the past two years Bell Laboratories has been working in cooperation with the National Aeronautics and Space Administration on Project Echo -- a first step in the experimental exploration of satellite communications.

ECHO I, the 100-foot, 10-story-high balloon, was placed in orbit on the morning of August 12th of ~~this year~~. 1960

ECHO I was launched by a three-stage Delta rocket. Douglas Aircraft Company is the prime contractor for this 92-foot rocket which has a maximum diameter of eight feet, weighs 112,000 pounds when fueled, and develops a thrust of 150,000 pounds at lift-off.

Placed atop the rocket's third stage was the deflated balloon, expertly folded into a 26-1/2 inch spherical container. The sphere was developed by NASA's Langley Research Center, Hampton, Virginia.

...All the expectant fathers who ever walked those long hospital corridors never walked with more hope, with more expectation, and with more apprehension than did the people who spent many sleepless nights participating in Project Echo...

At approximately 5:40 a.m., Eastern Daylight Time, on August 12, 1960, a three-stage Delta rocket carrying ECHO I roared off its launching pad at Cape Canaveral, Fla., and climbed high into the early morning sky. Directed into nearly perfect orbit by the Bell Laboratories' command guidance system, the rocket soon reached orbital altitude.

And then, at the exact instant of reaching its prescribed orbit, the spherical container was ejected, and some two minutes later was blown apart by an explosive. Thereupon the balloon was released and slowly inflated.

Three-quarters of an acre of aluminum-coated plastic went into the ECHO I balloon. The material was cut into 82 gores, each 48 inches wide and 157 feet long. The gores were fitted and cemented together in such a way that they would form a 100-foot sphere when inflated. In the early stages of folding, the balloon was held in place by huge clothespins. Later, it was encased in a vinyl sleeve and most of the air trapped inside was pumped out.

Moving in an almost circular orbit about 1,000 miles high, this extremely thin aluminum-coated plastic balloon, traveling almost 16,000 miles an hour, encircles the earth every two hours or, more exactly, every 118 minutes. This fast-moving balloon is an amazingly good spherical mirror: its reflectivity is 98 per cent or better for microwave frequencies up to 20 billion cycles per second.

The plastic itself is transparent, is 1/2,000 of an inch thick, and is called Mylar. One side of the plastic is covered with aluminum. This aluminum coat is superlatively thin, six-millionths of an inch. It is so thin that only 2-3/4 pounds of aluminum is needed to cover three-quarters of an acre of Mylar, thereby giving the balloon its brilliant, reflective finish.

ECHO I was used again and again to demonstrate two-way voice communication between the Bell Laboratories' Holmdel location in New Jersey and the NASA Jet Propulsion Laboratory's Goldstone installation in California.

We have installed at our Holmdel Space Communications Center a parabolic-dish antenna for transmitting (sending) messages and a scoop-shaped horn-reflector antenna for receiving them.

The 60-foot parabolic-dish antenna is mounted on a supporting tower. In action, the antenna is caused to continuously track, that is, to continuously point at and follow ECHO I with an accuracy of half a degree. It transmits at 960 megacycles, that is, 960 million cycles per second. The antenna radiates a sharply-focussed, 1-1/2 degree microwave beam which spreads out to a width of 26 miles at an altitude of 1,000 miles.

A nearby building houses a 10-kilowatt FM transmitter. What looks like a gangplank is actually a large rectangular waveguide which carries the transmitter output to the antenna system. Microwave power at these levels is hard to come by and must be conserved.

The receiving horn-reflector antenna was invented at the Laboratories in 1939 by Harald T. Friis, now retired, and A. C. Beck, who is at our Holmdel Laboratory. For ECHO I, reception is at a frequency of 2,390 megacycles per second. The horn-reflector antenna is accurately pointed towards and continuously follows ECHO I with an accuracy of one-tenth of a degree. A cab at the small end of the horn houses a supersensitive maser amplifier whose principal amplifying element is refrigerated down to 456 degrees below zero, Fahrenheit.

The word maser is coined from the phrase "microwave amplification by stimulated emission of radiation". The first radio maser was invented in the early 1950s by Dr. Charles H. Townes at Columbia University. Dr. Townes was formerly associated with Bell Laboratories.

An even more sensitive maser known as a three-level maser was invented by Professor Nicolaas Bloembergen of Harvard in 1956 and was first made to work in 1957 by Derrick Scovil, George Feher, and Harold Seidel, all of the Laboratories. They did more than just make it work. They were the first to build it in solid-state form. This particular three-level maser uses a ruby for its central element and is refrigerated by liquid helium.

This ruby, which is at the heart of the maser, is a six-inch rod-like industrial ruby. And chromium -- the chemical element that gives a ruby its distinctive hue -- likewise accounts for its amplifying properties, because in maser operation it is the chromium atoms that are stimulated to emit radiation. This type of maser generates 100 times less noise than comparable electron-tube amplifiers.

Noise

Speaking generally, we encounter three significant sources of noise: apparatus noise, cosmic noise, and atmospheric noise. Apparatus noise we avoid by using a maser amplifier. However, this in turn requires a large horn-reflector antenna to suppress microwave noise due to the heat of the earth. Cosmic noise we avoid by working at a high enough frequency. Atmospheric noise which we cannot avoid sets an upper limit to the usable frequencies for communicating between earth and space. Optimum frequencies lie between one and ten billion cycles per second.

It is important to note that we have been able to obtain close agreement between the calculated and measured values of atmospheric noise. Also, our over-all system noise is reasonably close to expectations.

We have achieved still another huge improvement in signal-to-noise ratio at the output of the system by using wide-deviation FM combined with a new type of FM detector that utilizes negative feedback.

Joseph G. Chaffee of the Laboratories, way back in 1933, invented this particular system of <u>negative feedback demodulation</u> in an FM receiver. This particular system of detection affords the best signal-to-noise ratio of any type of receiver known, thanks to negative feedback. It has been used successfully in recent satellite communication tests to reduce the noise output a hundred-fold.

Tracking

The signal reflected by ECHO I is very faint. And so, as you might readily guess, for successful communication, the large ground antennas which connect to powerful transmitters and superlatively sensitive receivers must at all times accurately point at and follow ECHO I as it rapidly sweeps across the sky. This is called tracking.

The problem of tracking has been solved. Every other second both Holmdel in New Jersey and Goldstone in California receive from NASA's Goddard Space Flight Center near Washington, D.C., a teletype communication in the form of a punched tape which tells them exactly how to point their respective antennas. Local electronic circuits use this information to cause the ground antennas to track ECHO I with high precision. Additional equipment at each terminal also provides radar and optical facilities for tracking ECHO I locally.

ECHO I Objectives

In addition to demonstrating successful two-way transcontinental telephony by way of an artificial passive satellite, ECHO I aims to provide information about: life expectancy of an inflatable, non-rigid, passive satellite; radio propagation, especially information near the horizon; damage due to micrometeroites; damage due to radiation; effect of light pressure and other factors on orbital stability; and so on.

5-Megacycle Passive Satellite Relay

If 24 100-foot passive satellites were put in randomly spaced polar orbits at an altitude of 3,000 miles, at least one would be mutually visible at Newfoundland and Scotland about 99 per cent of the time. For a five-megacycle base band, ground antennas over 100 feet in diameter would be required and transmitter powers would be measured in tens of kilowatts. Microwave bandwidth occupancy would be around 200 megacycles per second.

5-Megacycle Active Satellite Relay

The Laboratories is developing a 5-megacycle active satellite. This satellite carries essentially omnidirectional antennas, a one-watt radio transmitter, a radio receiver, power supply sources and so on. Such a satellite would be about four feet in diameter and weigh about 150 pounds. Bandwidth occupancy would be about 200 megacycles per second assuming a 1,000-watt ground transmitter and 60-foot ground antennas. The big advantage of an active satellite is that it permits a drastic reduction in the size of ground antennas and transmitter power.

While, of course, an active satellite doubles bandwidth occupancy, the net result is not necessarily a disadvantage. In fact, quite the contrary. Two important advantages concerning interference are realized when the low transmitter power, which an active satellite affords, is combined with Chaffee's FM receiver with feedback detector. First, the satellite system interferes less with other ground microwave systems and vice versa. Second, many satellites could operate in different parts of the sky simultaneously on the same radio-frequency band, interference being avoided by the directivity of the ground-station antennas.

5-Megacycle Stationary Satellite Relay

A stationary repeater in an equatorial orbit would be continuously visible over more than a third of the earth's surface. With oriented antennas, the one-watt radio transmitter would suffice for a 5-megacycle base band and could be used with a beam width just covering the earth.

Small indeed are the factors that tend to pull a stationary satellite relay off its precise orbit. The gravitational forces of the sun and moon, radiation pressure, and so on, cause significant orbital perturbations. Special space-borne equipment including jets, fly-wheels and electronic control equipment would, of course, be required in order to keep the satellite from wandering out of position.

Propagation time up to the satellite and back would be about three-tenths of a second. For some purposes -- for example, two-way telephony -- this noticeable time lag poses a problem.

Conclusion

All our familiar present-day domestic communication services are candidates for global communications via artificial earth satellites. However, as I mentioned earlier, only certain portions of the microwave radio-frequency spectrum are uniquely suited to this use. Our success is going to depend upon the wise use of these frequencies, For years we have had high hopes and now -- thanks to Project Echo -- we have lots of proof.